WAVELENGTH DIVISION MULTIPLEXING OPTICAL TRANSMISSION APPARATUS

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port is output through each corresponding output port. Since the above wavelength division multiplexing does not require all the output ports, only one of the output ports is used (signals $\lambda 1$ to $\lambda 4$ shown within the dashed lines on the input port side in the figure are output as a wavelength division multiplexed signal, $\lambda 1$ to $\lambda 4$, shown within the dashed lines on the output port side).

Here, as shown in Figure 3, the AWG 10 is generally fabricated as a wavelength combiner/splitter comprising two slab waveguides 18 and 19, having collimating and converging lens functions, integrated on a single substrate 17. The optical filter characteristics between the input and output ports of the AWG 10 have temperature dependence, the parameter being the length of each waveguide, so that the filter bandwidth fluctuates as the waveguide expands or shrinks due to changes in temperature. The fluctuation is the same for each channel, and a wavelength shift manifests itself as the same vector change on all channels.

Therefore, the AWG 10 incorporates a temperature control circuit 11 in order to stabilize the filter characteristics at the specified wavelength. Figure 1B shows a prior art configuration example of the temperature control circuit incorporated in the AWG. In the example shown here, a sensor resistor 15 having a stable resistance temperature coefficient and a heater resistive element 16 for generating heat proportionally to power consumption are mounted within the AWG, and further, circuits 13 and 14 for temperature control are provided that detect a change in the resistance of the sensor resistor 15 and supply current to the heater resistive element 16.

However, since its component parts themselves are subject to initial variations and other characteristic degrading factors such as temperature variations and aging, the prior art temperature control

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circuit, 13 to 16, has had the problem that if the initial variations existing in the component parts can be accommodated at the time of initial setting, there is no way to cope with the fluctuation of the filter center wavelength that may occur due to temperature variations of the parts, aging of the AWG, etc. during operation thereafter. As a result, the wavelength division multiplexing optical transmission apparatus has had to be designed by also considering wavelength stability degrading factors such as temperature characteristics and aging, and this has been one of the great barriers to the development of higher density wavelength division multiplexing optical transmission apparatus.

SUMMARY OF THE INVENTION

In view of the above-described problem, it is an object of the present invention to provide a wavelength division multiplexing optical transmission apparatus wherein, in addition to the prior art technique that detects and controls the temperature of the AWG which indirectly indicates the filter characteristics of the AWG, means for directly monitoring fluctuations in filter wavelength is incorporated in the AWG to directly detect the filter wavelength fluctuations caused by the temperature characteristics and aging of the component parts, and the temperature of the AWG is controlled in such a manner as to cancel the effect of the fluctuation.

In this way, not only at the time of initial setting, but during operation thereafter, the amount of wavelength fluctuation due to temperature variations and aging can be detected and controlled in a comprehensive manner, dramatically improving the stability accuracy of the AWG filter wavelength. As a result, a wavelength division multiplexing optical transmission apparatus having a higher density wavelength division multiplexing configuration can be achieved.

According to the present invention, there is provided a wavelength division multiplexing optical

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transmission apparatus comprising: an arrayed-waveguide grating having an output port and a plurality of input ports; light emitting means for generating a pilot signal to be input to one of the input ports; light detecting means for monitoring the pilot signal contained in a wavelength division multiplexed signal output from the output port; and a temperature control circuit for controlling the temperature of the arrayed-waveguide grating in such a manner as to cancel the amount of wavelength fluctuation occurring in the arrayed-waveguide grating and detected by monitoring the pilot signal.

The light emitting means is a wavelength tunable light source having a wavelength locking function, and generates signal light whose wavelength is swept within the bandwidth of the port at which the pilot signal is input. The light detecting means detects the amount of fluctuation in the filter characteristics of the port by detecting the swept signal light. The light emitting means comprises a plurality of light sources, and the light detecting means detects the amount of fluctuation in the filter characteristics of the port at which the pilot signal is input, by comparing received light levels between the plurality of light sources.

According to the present invention, there is also provided a wavelength division demultiplexing optical transmission apparatus comprising: an arrayed-waveguide grating having an input port and a plurality of output ports; light emitting means for generating a pilot signal to be input to the input port together with a wavelength division multiplexed signal; light detecting means for monitoring the pilot signal output from one of the output ports; and a temperature control circuit for controlling the temperature of the arrayed-waveguide grating in such a manner as to cancel the amount of wavelength fluctuation occurring in the arrayed-waveguide grating and detected by monitoring the pilot signal.

According to the present invention, there is further

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provided a wavelength division multiplexing optical transmission apparatus for transmitting a multiplexed signal carrying a first group of optical signals at different wavelengths, comprising: an arrayed-waveguide grating having a first output port from which is output the multiplexed signal carrying the first group of optical signals of different wavelengths respectively input from first to Nth input ports, and a second output port from which is output a multiplexed signal carrying a second group of optical signals of different wavelengths respectively input from the first to Nth input ports; light emitting means for applying a pilot signal having a wavelength belonging to the second group of optical signals to a corresponding one of the input ports; light detecting means for monitoring the pilot signal output from the second output port; and a temperature control circuit for controlling the temperature of the arrayedwaveguide grating in such a manner as to cancel the amount of wavelength fluctuation occurring in the arrayed-waveguide grating and detected by monitoring the pilot signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be more clearly understood from the description as set forth below with reference to the accompanying drawings.

Figure 1A is a diagram showing one configuration example (1) of a multiplexer/demultiplexer in a prior art wavelength division optical transmission apparatus.

Figure 1B is a diagram showing one configuration example (2) of the multiplexer/demultiplexer in the prior art wavelength division optical transmission apparatus.

Figure 2 is a diagram showing one example of an $n \times n$ frequency switching function of an AWG.

Figure 3 is a diagram showing one example of a wavelength splitter constructed from an AWG.

Figure 4 is a diagram showing a first embodiment of the present invention.

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Figure 5A is a diagram showing one example (1) of light emitting means and light detecting means in Figure 4.

Figure 5B is a diagram showing one example (2) of the light emitting means and light detecting means in Figure 4.

Figure 6A is a diagram showing one example (1) of the light emitting means of Figure 4 when it is constructed using a wavelength locker.

10 Figure 6B is a diagram showing one example (2) of the light emitting means of Figure 4 when it is constructed using the wavelength locker.

Figure 7 is a diagram showing an example of the light emitting means of Figure 4 when it is constructed from two light emitting means of different wavelengths.

Figure 8 is a diagram showing the basic principle of wavelength fluctuation detection to be performed in Figure 7.

Figure 9 is a diagram showing a second embodiment of the present invention.

Figure 10 is a diagram showing a third embodiment of the present invention.

Figure 11 is a diagram showing one example of a temperature control table used in Figure 10.

Figure 12 is a diagram showing a fourth embodiment of the present invention.

Figure 13 is a diagram showing a fifth embodiment of the present invention.

Figure 14 is a diagram showing the basic concept illustrating how one of the output ports on an AWG is configured into a dummy port.

Figure 15 is a diagram showing the basic principle of wavelength fluctuation detection to be performed in Figure 13.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Noting that the temperature dependence of each
filter wavelength of an AWG has the same vector for all

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ports, the present invention directly detects the fluctuation of the filter wavelength by utilizing the wavelength multiplexing function or nxn frequency switching function of the AWG and constantly monitoring the pilot signal applied to a predesignated dummy port. By feedback-controlling the temperature of the AWG in accordance with the result of the detection, the effect of the filter wavelength fluctuation is accurately canceled in such a manner as to offset the effects of the temperature characteristics and aging of its component parts, and the initially set conditions can thus be maintained.

Figure 4 is a diagram showing a first embodiment of the present invention.

This embodiment shows an example in which the present invention is applied to the transmitting side of a wavelength division multiplexing optical transmission apparatus. In Figure 4, one of the input ports on the AWG 10 which performs wavelength division multiplexing is preassigned for input of light of a wavelength different from any of the operating wavelengths λ_1 to λ_n used for signal transmission to the receiving side (the preassigned input port is hereinafter designated the dummy port 20). A light emitting means 21 for generating the pilot signal is connected to the dummy port 20 of the AWG 10, so that a wavelength division multiplexed signal carrying a total of (n+1) waves, i.e., the operating wavelengths $\lambda 1$ to λn plus the pilot signal, is output from the output port of the AWG 10.

The wavelength division multiplexed signal from the output port of the AWG 10 is split by a coupler (1×2 CPL) 23 into two outputs: one output signal (containing the pilot signal) is input to a light detecting means 22, and the other output signal is fed to an amplifier 24 where the signal power which dropped by 3 dB by the splitting into two outputs is amplified to its original level.

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invention, therefore, the optical amplifier is used as an ASE light source with no input light applied to it. In Figure 5A, the pilot signal of wavelength band λ_{n+1} different from any of the operating wavelengths λ_1 to λ_n described with reference to Figure 4 is generated by passing the ASE light from the ASE light source 31 through a narrowband filter 32, and the pilot signal thus generated is input to the dummy port 20 on the AWG 10.

Figure 5B shows one configuration example of the In this example, light detecting means 22 in Figure 4. the wavelength division multiplexed signal, λ_1 to λ_{n+1} , output from the AWG 10 is input to a narrowband filter 33 through which only the pilot signal λ_{n+1} , falling within the bandwidth of the dummy port, is allowed to pass. pilot signal λ_{n+1} is then input to a power meter 34 constructed from a photodiode (PD) or the like, where the fluctuation of the received signal level, that is, the amount of wavelength fluctuation caused by the fluctuation in the filter characteristics of the dummy port, is directly detected. Instead of the power meter 34, an optical spectrum analyzer 35 may be used to analyze the spectrum and detect the amount of wavelength fluctuation with higher accuracy. In this case, the filter 33 may be omitted.

Figures 6A and 6B are diagrams showing another example of the light emitting means 21.

In Figure 6A, the light emitting means 21 is constructed by combining a wavelength locker 38 with a laser diode (LD) 36 as a light source capable of outputting a signal of a highly stabilized wavelength. The wavelength locker 38 comprises two filters of different bands and photodiodes (PD1 and PD2), and the present wavelength is determined by performing a division between PD1 and PD2 (39); then, the wavelength is compared (40) with the reference (desired output

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wavelength of the LD 36), and the temperature of the LD 36 is controlled (41) based on the result of the comparison.

When the reference is varied, the emission wavelength of the LD 36 changes little by little as a result of the temperature control. Therefore, when the power meter 34 in Figure 5B is used in combination with the light source 21 that uses the wavelength locker, and the emission wavelength is swept little by little, the filter waveform (P-n to Pn) between the input and output ports on the dummy port 20 can be directly monitored, as shown in Figure 6B. According to this configuration, a function equivalent to the spectrum analysis performed using the optical spectrum analyzer 35 as the light detecting means 22 can be achieved using a PD power meter 34 of a simple construction.

Figure 7 is a diagram showing still another example of the light emitting means 21.

In this example, two light emitting means 21-1 and 21-2 of different wavelengths are used, and the output lights from the respective means are combined by a coupler (1×2 CPL) 42 for input to the dummy port 20 on the AWG 10. The light emitting means 21-1 and 21-2 are each constructed from the above-described light source that uses the wavelength locker, and the wavelength of one of the two light sources is slightly shifted toward the shorter wavelength side of the desired filter center wavelength λ_{n+1} of the dummy port 20, while the wavelength of the other light source is slightly shifted toward the longer wavelength side.

On the other hand, the optical spectrum analyzer 35 shown in Figure 5B is used as the light detecting means 22, and the difference between the two signal light levels is monitored. Alternatively, two sets of narrowband filters and power meters, each filter for passing therethrough corresponding one of the wavelengths

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of the two signal lights, may be provided one for each signal light; in this case, the wavelength fluctuation can be detected by monitoring the difference between the levels indicated by the two power meters.

Figure 8 shows the basic principle of the wavelength fluctuation detection performed using the two light emitting means 21-1 and 21-2.

In a stable condition, the signal light levels (P1 and P2) from the light emitting means 21-1 and 21-2 are equal to each other ($\Delta P = P1 - P2 = 0$), showing the signal detection level at the time of initial setting or during stable operation. Here, thin lines indicate the filter characteristics of the dummy port 20.

When the wavelengths drift in the longer wavelength direction, this means that the center wavelength of the filter characteristics is displaced in the longer wavelength direction due, for example, to a change in the temperature of the AWG 10; in this case, $\Delta P >> 0$. Conversely, when the wavelengths drift in the shorter wavelength direction, this means that the center wavelength of the filter characteristics is displaced in the shorter wavelength direction; in this case, $\Delta P << 0$. In this way, when two signals of different wavelengths are used, the direction of wavelength drift, etc. can be detected by just comparing the received light levels of the two wavelengths, or the amount of wavelength fluctuation can be detected from the amount of variation in the level difference between the two received wavelength signals. Therefore, wavelength control is applied to the AWG so that the center wavelength moves in the direction opposite to the direction of drift.

Figure 9 is a diagram showing a second embodiment of the present invention.

This embodiment shows an example in which the present invention is applied to the receiving side of a wavelength division multiplexing optical transmission

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apparatus. The AWG 10', temperature control circuit 11', coupler 23', light emitting means 21', light detecting means 23', and dummy port 20' at the receiving side are substantially the same as the corresponding components at the transmitting side previously described with reference to Figure 4, and their detailed configuration examples are also the same as those shown in Figures 5 to 8. Therefore, these components will not be further described here.

In the previously given Figure 3, the AWG 10 is shown as being used as a wavelength splitter at the receiving side, and the wavelength division multiplexed signal, λ_1 to λ_N , input to the input port is split into the respective wavelength signals λ_N for output through the respective output ports. In the present invention, one of the output ports is used as the dummy port. More specifically, the pilot signal applied from the light emitting means 21' is extracted from the dummy port 20', the characteristics of the AWG are detected by the light detecting means in the same manner as earlier described, and correction is applied from the temperature control circuit 11' in a similar manner.

Figures 10 and 11 are diagrams showing a third embodiment of the present invention.

As shown in Figure 10, in this embodiment, a controller 43 constructed from a microprocessor circuit is used to control the temperature control circuit 11 for the AWG 10; here, for the control operation, the controller 43 uses the temperature control table 44 shown in Figure 11. The temperature control table 44 stores reference voltage values for correcting for the amount of wavelength fluctuation detected by the light detecting means 22, and write values to a D/A converter (not shown) for generating the respective voltage values; the temperature control circuit 11 is controlled by the output of the D/A converter.

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In this way, using the temperature control table 44 and the amount detected by the light detecting means 22, the controller 43 applies appropriate correction to the amount of fluctuation, such as in the filter characteristics of the AWG 10, in accordance with a program using a prescribed correction algorithm incorporated therein. According to the methods described with reference to Figure 6(b) and Figure 8, the need for the temperature control table 44 can be eliminated if the algorithm is written so as to bring the center wavelength of the filter to the specified wavelength in the former case, or so as to reduce the difference between the two received light levels to zero in the latter case.

Figure 12 is a diagram showing a fourth embodiment as a modification of the configuration of Figure 4. Likewise, Figure 13 is a diagram showing a fifth embodiment as a modification of the configuration of Figure 7.

In the embodiment of Figure 4, the dummy port 20 has been provided only on the input side, but in the fourth embodiment, a dummy port 51 for monitoring is provided on the output side of the AWG 10 in addition to the one on the input side. In the fifth embodiment, a plurality of dummy ports 51 to 54 are provided on both the input and output sides of the AWG 10.

Figure 14 is a diagram showing the basic concept illustrating how one of the output ports on the AWG 10 is configured into a dummy port.

Figure 14 shows an example of the AWG 10 constructed as a simple 3 \times 3 matrix. As shown by dashed lines in the figure, on the input side, two operating input ports (OPTIN1 and OPTIN2) are assigned for signal lights of wavelengths $\lambda_1(1)$ and $\lambda_2(5)$, respectively, and the remaining input port (dummy port) is assigned for the pilot signal of wavelength $\lambda_1(7)$. With these assignments, on the output side, a wavelength division

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(6), with the occidence of the input side input. (8); and (9) on the input side are not input. as described in and input signal lights as described in and input signal input. The assignments of signal input. With the assignments of signal rigures 12 and 13 can make configurations shown in the configurations of remitter above. The achieved with simple circuitrus above. apover the configurations shown in Figures 12 and 13 can the configurations shown in These configurations amplifier 24 at the achieved with simple circuitry. 23 and amplifier 24 at the achieved the need for the coupler 23 and amplifier 24 at the liminate the need for the coupler 23 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 24 at the need for the coupler 25 and amplifier 25 and amplifier 24 at the need for the coupler 25 and amplifier 25 and ampl be achieved with simple circuitry. 23 and amplifier 24 at the coupler and the eliminate the need for the coupler 23 and amplituer 42 in right the transmitting side in reductions in hardware and the transmitting reductions in high red Figure 1, achieving reductions in nardware and the elimination of the furthermore, able to provide manufacturing costs. manutacturing costs. Furthermore, the elimination of the the provide the advantage of being able to provide the advantage of being the loss due to coupler 23 offers the advantage of since the loss due to provide the loss d 5 coupler 23 offers the advantage of being the loss due to provide the loss due to algorithm and the loss of the los a sutticient received not occur. There is also offered splitting etc. the narrowhand filter (33 in riminal splitting) Splitting, etc. does not occur. There is also officered (33 in Figure) that the narrowband filter the advantage that the nailot signal that the nailot the advantage that the pilot signal therethrough can be for passing only the pilot detection means 22. 10 and row passing only the light detecting means 22. Inaced from the the basic principle of the rigure 15 shows wavelength fluctuation detection right plant in magne 21-1 and 21-2 in right In the previously described example of Figure 11. wavelength means 21-1 and 21-2 in Figure 13. In the previously described example of Figure 8, in the previously different wavelengths are input in the slightly different wavelengths are input in the previously described example of Figure 8, and in the previously described example of Figure 8, and in the previously described example of Figure 8, and in the previously described example of Figure 8, and in the previously described example of Figure 8, and in the previously described example of Figure 8, and in the previously described example of Figure 8, and in the previously different wavelengths are input in the previously different wavelengths. signals of slightly different wavelengths are input in the within the bandwidth of the dummy port, but in the within Within the pandwidth of the dummy port, the recording dummy within the pandwidth pilot signals of wavelengths dummy port, the recording dummy port, the port, the recording dummy port, the dummy port, the recording dummy port, the dumm example snown nere, pliot signals or wavelengths located dummy norts is in different bandwidths are input to one of the dummy norts in different sand sand here. In different pandwidths are input to the respective dimmy ports is ports 53 and 54.

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ports 53 and 54. ports 33 and 34. Here! to one of the auminy ports is shifted by AN whose wavelength is shifted by an input the pilot signal whose wavelength is the pilot signal who wavelength is the pilot signal wavelength is the pilot signal who wavelength is the pilot signal who wavelength is the pilot signal who wavelength is the pilot signal wavelength is the pilot signal who wavelength is the pilot signal who wavelength is the pilot signal wavelength is the pi 20 LINGUL CIRCE WAVELENGTH IN the Shorter wavelength the from its center wavelength and the shorter wavelength from its center wavelength in the other dummy nort is innut the from its center wavelength. trom its center wavelength in the shorter wavelength the dummy port is input the dummy port is input to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction, while to the other dummy port is objected by An from its direction. pilot signal whose wavelength is shifted by Al from its center wavelength the direction of the fluctuation wavelength the direction of the fluctuation of the direction of the direction of the fluctuation of the direction of the direction of the fluctuation of the direction of the fluctuation of the fluctuatio 25 As a result, the direction of the fluctuation of the fluctuation of the filter wavelength fluctuation filter wavelength freceived light 30 35

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is opposite between the two pilot signals. Therefore, the amount of wavelength fluctuation can be detected by comparing the received light levels of the two different wavelength signals, as in the case of the previously described example of Figure 8. For the detailed operation, refer to the description given with reference to Figure 8. In the configuration of Figure 13, since there is no need to separate the two pilot signals of different wavelengths on the output side, power meters of simple construction need only be connected to the respective output ports 51 and 52, eliminating the need for an expensive optical spectrum analyzer to detect the two wavelengths.

As described above, according to the present invention, means for directly monitoring filter wavelength fluctuation is incorporated in the AWG, to directly detect the filter wavelength fluctuation resulting from the temperature characteristics and aging of its component parts, and control is performed in such a manner as to cancel the effect of the fluctuation. This offsets the effects of the temperature variations, aging, etc. of the component parts and, by detecting the amount of wavelength fluctuation caused by such variations, etc. and performing control so as to cancel the effect of the fluctuation, the stability and accuracy of the filter wavelength of the AWG can be dramatically enhanced and maintained for an extended period of time. As a result, a wavelength division multiplexing optical transmission apparatus having a higher density wavelength division multiplexing configuration can be achieved.